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DISTRIBUTION OF GIBBSITE AND KAOLINITE WITH DEPTH IN A GIBBSITIC SOIL ON KAUAI

W. E. Holmes, Makoto Takahashi,† and G. Donald Sherman‡*

Gibbsitic soils of Hawaii have been described by Sherman *(2)*. These soils are located on all major islands, and they have received serious consideration by mining companies as possible sources of bauxite. Because such soils may eventually be mined, the University of Hawaii was authorized by the 1957 Territorial Legislature to conduct experiments in the revegetation of a simulated stripmined area. An area was selected in the Wailua Game Refuge on Kauai as an experimental area. In order to evaluate an appropriate depth at which to terminate the simulated mining operations, analytical data were needed. These data were obtained from borings taken from the experimental area prior to starting the excavation. The purpose of this report is to describe the chemical and mineral composition of the bauxite deposits on the island of Kauai.

EXPERIMENTAL PROCEDURES

Sampling: Thirteen borings were made over the experimental area. The borings were made after 1.0 to 1.5 feet of topsoil had been removed. A 3-inch diameter, hand-operated soil auger was used. Samples were taken at 1-

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foot intervals to depths ranging from 15 to 20 feet. A single boring was taken to a depth of 35 feet, of which the last 20 feet were done after the excavation of 14 feet. Each sample was placed in a plastic sack for shipment to the laboratory of the Department of Agronomy and Soil Science, for analysis.

Upon arrival at the laboratory, each sample was thoroughly mixed, and a small representative portion of the sample was obtained by successive quarterings. This small sample was dried at 60°C., ground to pass through a 60-mesh sieve, then placed in a labelled vial to be saved for differential thermal analysis. The major portion of the initial moist sample was returned to the plastic sack to be preserved for a sieving analysis.

Differential thermal analysis: A portable differential thermal apparatus designed for rapid analyses was used. The procedure differed from that described by Norton *(1)* in that the rapid procedure made use of a fast, nonuniform heating rate. The temperature range used was from room temperature to about 650° C. This range permitted observing the characteristic endothermic reactions of gibbsite and kaolinite with the apparatus employed. A sample of bauxite (gibbsite) designated as Dana 261 was used as a reference sample for estimating the percentages of gibbsite. The reference sample for estimating the percentages of kaolinite was labelled Dana 492. The origins of the gibbsite and kaolinite reference samples were, respectively, Little Rock, Arkansas, and the McNamee Mine in South Carolina.

Sieving analyses: These analyses were conducted to determine the distribution of gibbsite and kaolinite with respect to size of the soil particles and aggregates. The moist samples saved after sampling for differential thermal analyses were used. In order to have sufficient sample for sieving analyses, the samples were composited such that each sample used for sieving represented increments of depth ranging from 3 to 6 feet.

For each sieving analysis a sample of some 500 to 600 grams of moist soil was used. From this, three samples ranging from 30 to 50 grams were taken for a moisture determination. The moisture determination was necessary for making all calculations on a dry weight basis. Prior to sieving, each sample was stirred in an aqueous suspension for 20 minutes with a laboratory stirring device. A series of sieves which included the 9-, 16-, 32-, 60-, 115-, and 200-meshes per inch sizes were used, but only the data of the 60-mesh sieve are used in this report. The material remaining on each of these sieves was collected, dried at 105° C., and weighed. The percentages retained on each sieve were calculated using the estimated oven dry weight of the initial moist sample. This estimate was made using the information gained from a moisture determination. Small portions of each dried sample were prepared for differential thermal analysis in order to observe the distribution of gibbsite and kaolinite in each size fraction.

RESULTS AND DISCUSSION

Variability in distribution of gibbsite and kaolinite: The data obtained from the differential thermal analysis are presented in table 1. Although the two sites studied are part of the same ridge and are essentially contiguous, being separated by a narrow neck about 300 feet long, gross inspection of the data between the two sites indicates distinct differences in the concentration and depth of gibbsite deposits. Subsequent stripping operations indicated some differences in the ore body. Some difference was noted in the character of the weathered rocks. In the East site, nodules and fragments of gibbsite were frequently encountered over the entire area but none was found in the West site.

Because of the apparent differences between the two sites, data were recorded and treated separately. Data on differential thermal analyses of averages of five borings taken from the East site and the averages of eight borings taken from the West site are presented in table 1. Since many of the reports on bauxite research present their data in terms of alumina (Al_2O_3) instead of gibbsite, the alumina equivalent has also been included in the table. The following conversion factor was used: 100% gibbsite = 65% alumina.

In the East site the content of gibbsite increases with increase in depth up to the 8-foot depth and thereafter there is a steady decline with some minor fluctuations. On the other hand, in the West site gibbsite content remains at relatively uniform level up to the 8-foot depth and diminishes thereafter with increase in depth. With the exception of the first foot of sampling, the East site has materially higher gibbsite content for all levels of depth than those of corresponding depths in the West site. In nine of the foot-interval samples, those from the East site had double the gibbsite content as compared to the corresponding samples from the West site. The differences in gibbsite content for corresponding depths for the two sites are presented in table 3.

Individual borings highly variable: Marked variations were noted between borings. The extent of variability between the different borings can be readily seen by inspection of figure 1, in which the first three borings taken from the East site were plotted out individually. The case history of boring No. 3 is especially an interesting one. At the 6-foot depth it recorded the highest gibbsite content of 52 percent out of a total 244 readings taken. However, from the 7-foot depth on, the content of gibbsite dropped abruptly and none was recorded from the 12- to the 18-foot depth.

Because of the great variability in individual borings, for assaying any prospective individual bauxite ore body site, a minimum of three borings should be taken.

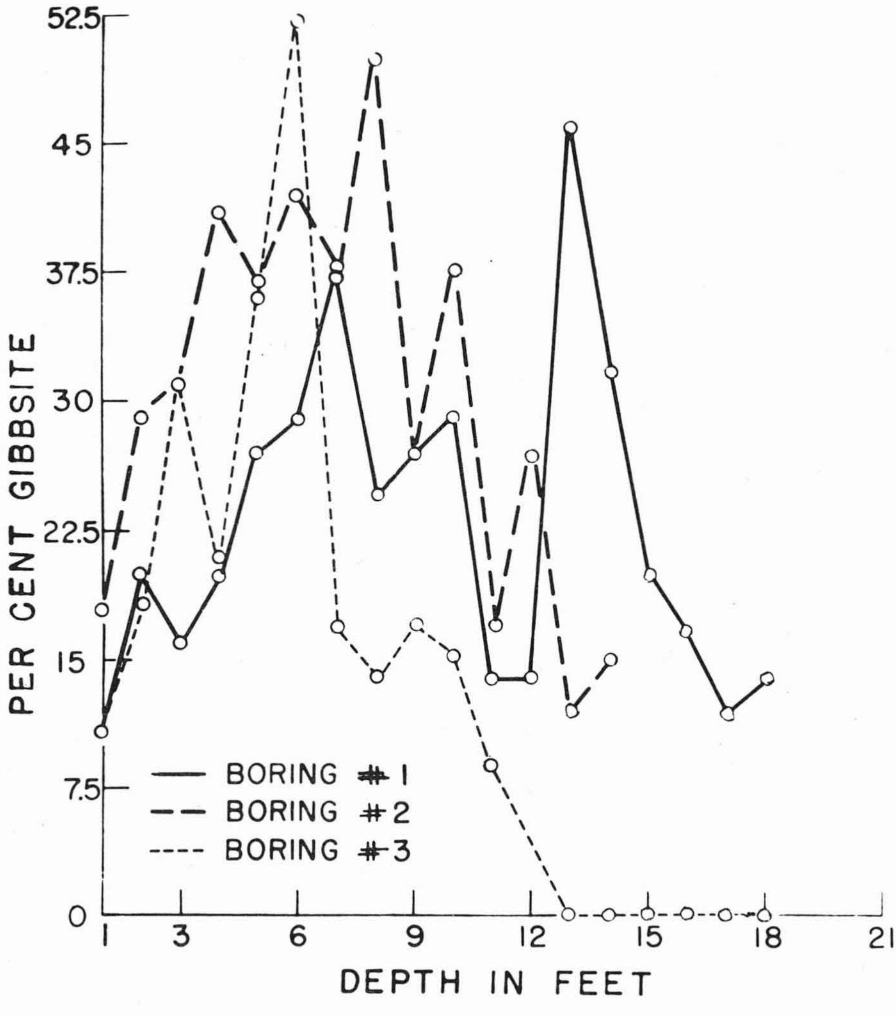

Figure 1. Distribution pattern of gibbsite in the first three borings taken from the East site.

Kaolinite—its distribution and relation to gibbsite: Examination of data presented in table 1 clearly indicates that the content of kaolinite increases with depth. In general, kaolinite content increased very slowly for the first 8 to 10 feet of depth but from 8 to 10 feet to the 18-foot depth it increased progressively with each increase in depth. Examination of the analyses of gibbsite and kaolinite indicates high correlation. The precise relationship between these two components was explored statistically by working out the regression equation. The results of the statistical analysis show a linear regression relationship between kaolinite and gibbsite.

TABLE 1. Tabulation of gibbsite content and percentage difference of two sites at varying depths from 1 to 18 feet

Depth in feet	Percent gibbsite, East site	Percent gibbsite, West site	Difference between two sites	Percent increase or decrease in gibbsite content — East over West site
1	15.6	18.6	- 3.0	- 10.6
2	23.8	20.6	+ 3.2	+ 15.5
3	24.8	20.0	+ 4.8	+ 24.0
4	33.4	25.5	+ 7.9	+ 31.1
5	29.8	20.2	+ 9.6	+ 47.3
6	37.0	18.6	+18.4	+ 98.3
7	39.4	21.0	+18.4	+ 87.6
8	29.4	14.0	+15.4	+102.3
9	24.6	10.7	+13.9	+129.1
10	30.8	13.5	+17.3	+127.9
11	17.8	10.3	+ 7.5	+ 73.4
12	17.0	10.1	+ 6.9	+ 69.0
13	23.2	10.1	+13.1	+130.3
14	14.2	9.6	+ 4.6	+ 47.3
15	10.2	9.8	+ 0.4	+ 4.0
16	20.7	6.6	+14.1	+121.3
17	15.7	3.3	+12.4	+254.9
18	14.0	5.3	+ 8.7	+ 96.3

Distribution of gibbsite and kaolinite in various size fractions: Data presented in table 2 show the distribution of gibbsite and kaolinite in the fractions greater and less than 60-mesh in size. The data are from 4 of the 13 borings made in the two excavation areas. The percentages of gibbsite and kaolinite are weighted averages calculated from data presented in the appendix.

Within the upper 10 to 12 feet of the four borings, an average of 41 percent of the material was retained on a 60-mesh sieve. This average figure may be somewhat high for samples from this area because of an unusually high value of 61 percent observed in hole No. 6 of the West excavation site. The average of the other five borings is but 34 percent, The average gibbsite content in the greater than 60-mesh fraction was found to be 45 per cent, which compares to 25 percent observed in the unfractionated soil. Kaolinite in the greater than 60-mesh fraction was essentially the same as that of the unfractionated soil. An average gibbsite content of only 21 percent was found in the less than 60-mesh fraction, and the kaolinite content also was not essentially different from that of the unfractionated soil; i.e., 2 to 3 percent.

TABLE 2. Distribution of gibbsite and kaolinite in the size fractions greater and less than 60-mesh

Depth, feet	Fraction	Percentage of total sample	Percent gibbsite	Percent kaolinite
		Hole No. 1, East excavation		
3 – 11	60 mesh	27	67	0
	60 mesh	67	18	0
12 – 20	60 mesh	21	43	12
	60 mesh	77	7	16
		Hole No. 4, East excavation		
1 – 10	60 mesh	31	38	6
	60 mesh	66	12	12
11 – 20	60 mesh	26	4	59
	60 mesh	70	5	54
		Hole No. 5, East excavation		
1 – 10	60 mesh	45	44	0
	60 mesh	55	33	0
11 – 19	60 mesh	24	69	1
	60 mesh	76	28	6
		Hole No. 6, West excavation		
1 – 8	60 mesh	61	30	0
	60 mesh	36	20	0
9 – 20	60 mesh	56	8	32
	60 mesh	43	4	30
		Averages of four holes, fractions		
1 – 10	60 mesh	41	45	2
	60 mesh	55	21	3
10 – 20	60 mesh	32	31	26
	60 mesh	67	11	27
		Averages of unfractionated soil		
1 – 10	Entire soil	–	25	3
11 – 20	Entire soil	–	17	29

TABLE 3. Chemical analyses of a Kapaa silty clay profile within the reclamation project, Wailua, Kauai

Depth, inches	Silica (SiO_2), percent	Alumina (Al_2O_3), percent
0 - 10	6.58	29.76
10 - 15	1.85	31.44
15 - 30	0.90	37.44
30 - 69	0.69	42.32
69 - 74	0.70	40.16
74 - 77	0.73	41.32
77 - 93	0.67	42.16
93 - 103	0.72	40.40
103 - 104	0.59	37.60
104 - 128	2.18	29.12
128 - 130	4.27	31.20
130 - 136	5.71	28.48
136 - 146	18.50	29.04
146 - 150	8.85	40.48
150 - 160	21.79	29.28
160 - 170	9.02	45.92

Within the 10- to 20-foot depth, the average gibbsite content of the greater than 60-mesh fraction was 31 percent, which compares to 17 percent for the average of the unfractionated soil from that depth. Kaolinite content, however, in the greater than 60-mesh fraction was found to be 26 percent, which is not essentially different from that of either the less than 60-mesh fraction or the unfractionated soil.

Comparison of differential thermal data with those from chemical analyses. Table 3 presents data from a single sampling in the same area from which samples for the differential thermal data were obtained. The samples used for the analyses represented in table 3 are not the same as those used for the differential thermal data presented in table 1, but are taken from an adjacent site. In the differential thermal data of table 1 the percentages of kaolinite and gibbsite are, respectively, measures of the percentages of silica (SiO_2) and alumina (Al_2O_3). Data in table 3 are expressed as silica and alumina. For purposes of comparison, kaolinite is 46 percent silica and 40 percent alumina.

Keeping in mind that gibbsite is but 65 percent alumina, a comparison of the data of table 3 with those of table 1 shows that at depths up to 10 feet the differential thermal data tend to underestimate the percentage of alumina. This conclusion that the differential thermal data tend to underestimate the percentage of alumina appears to be justified because, within the top 10 feet, several of the samples of table 3 analyzed 40 percent alumina. This corresponds to a gibbsite percentage of 60, which is higher than any of the samples reported in table 1. The alumina contributed by kaolinite is negligible at depths less than 10 feet. Also, the data of table 3 show a low silica content at depths less than 10 feet. This is in accord with the low kaolinite percentages shown at similar depths as shown in table 1. Thus, even though the differential thermal data differ from those of chemical analyses, the same trends are shown; namely, low silica or kaolinite accompanied by high alumina or gibbsite at depths less than 10 feet and increasing silica or kaolinite accompanied with decreasing alumina or gibbsite at lower depths. Subsequent investigation indicates that a large proportion of the alumina exists as hydrated ferruginous-alumina gel and thus is not reflected in the differential analysis.

SUMMARY

Borings were made in a gibbsitic area within the Wailua Game Refuge of Kauai. The area was excavated for an experiment in revegetation of a simulated stripmined area.

Differential thermal analyses of soils from the borings showed that within the first 10 feet, gibbsite predominates over kaolinite, but between 10 and 20 feet, there is a gradual decrease in gibbsite which is accompanied by a sharp increase in kaolinite. Also within the first 10 feet, material retained on a 60-mesh sieve is substantially higher in gibbsite than is either the less than 60-mesh fraction or the unfractionated soil. Within this depth (1 to 10 feet) the content of kaolinite in the fractions and in the unfractionated soil averaged but 2 to 3 percent.

Within the 10- to 20-foot depth, gibbsite was higher in the greater than 60-mesh fraction than in either the less than 60-mesh fraction or the unfractionated soil. However, kaolinite content of this fraction did not differ materially from that of the unfractionated soil.

Chemical analyses showed that the gibbsite percentages obtained from rapid differential thermal procedures underestimated the alumina present in the 1- to 10-foot depths and that its values could not be used to evaluate the ore for commercial purposes. These data indicate a large portion of the alumina is in a hydrated amorphous state, probably a ferruginous-aluminous gel.

LITERATURE CITED

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2. Sherman, G. Donald. 1958. Gibbsite-rich soils of the Hawaiian Islands. Hawaii Agr. Expt. Sta. Bul. 116.

APPENDIX 1a

Table 1. Differential thermal data from five borings in the East excavation site

	Hole No. 1			Hole No. 2			Hole No. 3		
Depth, feet	Sample number	Gibbsite, percent	Kaolinite, percent	Sample number	Gibbsite, percent	Kaolinite, percent	Sample number	Gibbsite, percent	Kaolinite, percent
1	58- 1B	11	0	58-84B	18	0	58- 98B	11	0
2	58- 2B	20	0	58-85B	29	0	58- 99B	19	0
3	58- 3B	16	0	58-86B	31	0	58-100B	31	0
4	58- 4B	20	0	58-87B	41	0	58-101B	21	0
5	58- 5B	27	0	58-88B	37	0	58-102B	36	0
6	58- 6B	29	0	58-89B	42	0	58-103B	52	0
7	58- 7B	37	0	58-90B	38	0	58-104B	17	0
8	58- 8B	25	0	58-91B	50	0	58-105B	14	0
9	58- 9B	27	0	58-92B	27	0	58-106B	17	14
10	58-10B	29	0	58-93B	38	0	58-107B	15	8
11	58-11B	14	10	58-94B	17	0	58-108B	9	35
12	58-39B	14	10	58-95B	27	5	58-109B	0	31
13	58-40B	46	5	58-96B	13	13	58-110B	0	—
14	58-41B	32	10	58-97B	15	14	58-111B	0	22
15	58-42B	20	10				58-112B	0	50
16	58-43B	17	20				58-113B	0	40
17	58-44B	12	20				58-114B	0	24
18	58-45B	14	20				58-115B	0	54
19	58-46B	14	20						
20	58-47B	15	40						
21	58-48B	0	52						
22	58-49B	7	43						
23	58-50B	11	23						
24	58-51B	10	23						
25	58-52B	0	43						
26	58-53B	0	35						
27	58-54B	0	53						
28	58-55B	5	42						
29	58-56B	8	40						
30	58-57B	31	21						
31	58-58B	35	18						
32	58-59B	5	79						
33	58-60B	3	48						
34	58-61B	0	53						

APPENDIX 1b

Table 1. (Continued)

	Hole No. 4			Hole No. 5		
Depth, feet	Sample number	Gibbsite, percent	Kaolinite, percent	Sample number	Gibbsite, percent	Kaolinite, percent
1	58-227B	26	0	58-245B	12	0
2	58-228B	33	0	58-246B	18	0
3	58-229B	23	0	58-247B	23	0
4	58-230B	42	7	58-248B	43	0
5	58-231B	24	12	58-249B	25	0
6	58-232B	23	9	58-250B	39	0
7	58-233B	45	9	58-251B	60	0
8	58-234B	13	18	58-252B	45	0
9	58-235B	13	21	58-253B	39	0
10	58-236B	22	47	58-254B	50	0
11	58-237B	6	73	58-255B	43	0
12	58-238B	5	41	58-256B	39	2
13	58-239B	24	69	58-257B	33	0
14	58-240B	0	95	58-258B	24	3
15	58-241B	3	44	58-259B	18	0
16	58-242B	6	72	58-260B	39	6
17	58-243B	2	88	58-261B	33	10
18	58-244B	3	48	58-262B	25	0
19				58-263B	26	16

APPENDIX 2a

Table 2. Differential thermal data from eight borings in the West excavation site

	Hole No. 1			Hole No. 2			Hole No. 3		
Depth, feet	Sample number	Gibbsite, percent	Kaolinite, percent	Sample number	Gibbsite, percent	Kaolinite, percent	Sample number	Gibbsite, percent	Kaolinite, percent
1	58-264B	23	0	58-183B	15	0	58-319B	15	0
2	58-265B	24	0	58-184B	—	—	58-320B	19	0
3	58-266B	27	0	58-185B	13	0	58-321B	15	0
4	58-267B	46	2	58-186B	31	0	58-322B	14	0
5	58-268B	23	0	58-187B	18	8	58-323B	12	0
6	58-269B	29	0	58-188B	16	21	58-324B	14	0
7	58-270B	23	3	58-189B	21	2	58-325B	13	2
8	58-271B	17	3	58-190B	17	9	58-326B	6	21
9	58-272B	19	8	58-191B	12	3	58-327B	11	15
10	58-273B	24	15	58-192B	14	10	58-328B	13	22
11	58-274B	15	4		—	—	58-329B	11	16
12	58-193B	21	9	58-175B	17	24	58-130B	15	—
13	58-194B	14	21	58-176B	6	29	58-131B	21	—
14	58-195B	3	30	58-177B	1	22	58-132B	21	29
15	58-196B	11	24	58-178B	2	56	58-133B	9	21
16	58-197B	3	63	58-179B	3	65	58-134B	7	9
17	58-198B	3	33	58-180B	8	31	58-135B	5	49
18	58-199B	—	—	58-181B	6	69	58-136B	0	25
19	58-200B	7	41	58-182B	19	0	58-137B	0	53
20							58-138B	0	51

APPENDIX 2b

Table 2. (Continued)

Depth, feet	Hole No. 4			Hole No. 5			Hole No. 6		
	Sample number	Gibbsite, percent	Kaolinite, percent	Sample number	Gibbsite, percent	Kaolinite, percent	Sample number	Gibbsite, percent	Kaolinite, percent
1	58-308B	20	0	58-286B	14	0	58-275B	8	0
2	58-309B	23	0	58-287B	17	0	58-276B	10	0
3	58-310B	27	0	58-288B	20	0	58-277B	8	4
4	58-311B	36	0	58-289B	20	4	58-278B	27	0
5	58-312B	21	0	58-290B	30	0	58-279B	8	3
6	58-313B	23	0	58-291B	19	0	58-280B	15	3
7	58-314B	32	0	58-292B	13	9	58-281B	37	0
8	58-315B	23	0	58-293B	5	6	58-282B	19	0
9	58-316B	7	6	58-294B	12	13	58-283B	0	5
10	58-317B	33	0	58-295B	11	4	58-284B	2	2
11	58-318B	16	10	58-296B	11	6	58-285B	5	16
12	58-166B	17	25	58-148B	15	14	58-157B	25	39
13	58-167B	15	20	58-149B	10	45	58-158B	11	—
14	58-168B	23	11	58-150B	8	15	58-159B	20	15
15	58-169B	23	13	58-151B	4	13	58-160B	17	33
16	58-170B	23	19	58-152B	4	39	58-161B	11	19
17	58-171B	7	21	58-153B	—	—	58-162B	0	33
18	58-172B	19	36	58-154B	—	—	58-163B	7	13
19	58-173B	14	37	58-155B	5	32	58-164B	0	—
20	58-174B	0	41	58-156B	50	32	58-165B	0	33

APPENDIX 2c

Table 2.(Continued)

	Hole No. 7			Hole No. 8		
Depth, feet	Sample number	Gibbsite, percent	Kaolinite, percent	Sample number	Gibbsite, percent	Kaolinite, percent
1	58-297B	20	0	58-218B	34	0
2	58-298B	18	3	58-219B	33	0
3	58-299B	17	6	58-220B	33	0
4	58-300B	15	10	58-221B	15	4
5	58-301B	14	11	58-222B	36	5
6	58-302B	30	3	58-223B	17	13
7	58-303B	12	24	58-224B	17	10
8	58-304B	12	25	58-225B	13	20
9	58-305B	14	22		—	—
10	58-306B	8	42	58-226B	3	67
11	58-307B	4	44		—	—
12	58-139B	0	42	58-211B	1	82
13	58-140B	0	64	58-212B	4	25
14	58-141B	0	64	58-213B	1	57
15	58-142B	9	28	58-214B	3	70
16	58-143B	0	20	58-215B	2	44
17	58-144B	0	72	58-216B	0	47
18	58-145B	0	63	58-217B	0	60
19	58-146B	0	75		—	—
20	58-147B	0	60		—	—

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